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and the subsequent parallelism, calls for candid intercourse, for free and constant interchange, between the values of life and its machinery. Thanks to the too-persistent past, civilization is still suffering from the divorce of these, involving a separation of ends and means, of life's ideal purposes and loyalties and its instruments. Doubtless, at least as must appear in retrospect, such a separation was natural during a militaristic and absolutistic social order. It may have had, too, some point during the earlier years or centuries of the succeeding industrial organization of society, when interest in mere conquest still gave sanction to the principle that life's ends justify any means. But, if industrialism and its accompanying democracy are to prove productive, making some contribution to civilization, the separation can not continue. Thus the soldier, destined for another world, has too long been the romantic figure. The mechanic, master of this world and working for results here, must henceforth take first place in romantic interest. Culture and ideality generally have too long stood aloof, idealizing the past and dreaming, however beautifully, of the future, and practical life, machinery its instrument and science its law, has too long been just practical or "efficient." Culture and efficiency, ideality and practicality, life's deep human values and its nowadays wonderfully devised and wonderfully effective instruments must be wedded as never before, state and school and church all so reorganizing themselves as to make the union, in the first place, quite possible and, in the second place, as it is realized, positively effective. Pragmatism, involving as it does the union of ideality and practicality, or spirituality and real life, of values and instruments, would change the present. Eschewing metaphysics, it would itself realize something.

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THE NATURE OF SCIENTIFIC MATTER

SCIENCE has both form and matter. The form of science known as scientific method is concerned with the ways of observation and experimentation, the kinds of classification, the nature and derivation of scientific laws, and the like. It is the machinery which transforms mere fact into scientific knowledge. It has been carefully examined and is discussed in nearly every book on logic. There has been a tacit assumption, moreover, that the form is all there is to science; that it makes no difference what the matter is so long as the form is correct; that, in short, any rubbish can be put into the machine and come out science. The assumption simply is not true. Just as much care has to be taken of the matter of science as of its form. If not, the machine clogs at a certain point and the matter can not be refined any further. Yet the matter of science has been most strangely neglected.

The matter of science is what science describes, the objects about which laws are made. With a few exceptions it is the data of science. Now, unless science is to be a mere catalogue of curious events, it is apparent that facts must be comparable with one another. Without the means of comparing facts no laws could be made, no system organized. High degree of system is possible only where there is high degree of comparability. Consequently, just as the degree of advancement of a science may be estimated on its formal side by its degree of systematization, it may be estimated on its material side by its degree of comparability. The principle which governs the material side of science throughout is comparability. The evolution of scientific matter appears as a continuous endeavor to reach a least common denominator of facts.

This endeavor is marked by three stages: First, an interpretation of all facts in terms of data of a common sense. Secondly, a reduction of these data to certain entities called units. Thirdly, a reduction of these units to certain elementary units. I will examine each of these stages separately.

First, it is necessary to find an interpretation of all facts in terms of a common sense. For if we cast off for a moment all our scientific learning and consider the various senses as the simplest savage might, they will appear to us as so many little islands with impassable gulfs between. How could one see a sound, how taste a sight, or smell a prick? Each sense seems cut off from every other, and there seems to be no means of communication among them. Yet in spite of this apparent incommunicability, we know that a single object can be experienced in a multitude of senses. I see a rose, hear its rustle, smell its fragrant odor, and am pricked by its thorns. There seems to be a certain parallelism of the senses such that within limits they can be compared point for point. We can not see roughness, but we can see a corrugated surface and correctly interpret that as roughness. Then we can dispense with the sense of touch so far as it informs of roughness.

This power of interpreting one sense in terms of another is extremely important for science. For our experience, the crude facts, comes to us through many senses, so that if we could not interpret one sense in terms of another, the facts coming to us from each of the senses would be totally isolated from those coming to us from any of the others. Comparability of facts would then only be possible within a sense. There might be many little sciences, one for each sense, but no science. The first step therefore, that science must make towards comparability of facts is the interpretation of all facts in terms of a single sense. What sense will that be?

Just exactly why *a priori* science should choose sight, I do not know. There is no one characteristic by which sight can claim a clear superiority above all the other senses. It is very sensitive, but probably not more so than hearing or even smell. It has one great advantage over hearing and smell, however, in that it can sense a number of objects at the same time clearly distinguished from one another, while hearing and smell blend and confuse their objects. But sight must share this advantage with any of the touch senses. The combination of clearness and delicacy, however, makes a sense peculiarly well adapted for measurement. Besides, sight is the best distance sense, the most accurate in determining directions as well as the one able to inform of objects furthest away. It is probably the combination of all these qualities rather than any one of them that decided scientific preference in its favor.

But if there is no incontrovertible *a priori* proof why sight should be the scientific sense, there is abundant *a posteriori* proof in the sciences. I shall summarize the data employed in determining the principal facts in the science of sound. It is apparent that the natural sense to use in observing the facts of sound is hearing, and if sight is employed even here, there must be a strong predisposition on the part of science in favor of sight.

The principal facts about sound are pitch, loudness, quality, velocity, reflection, refraction, and interference.

The pitch of sound is determined by the number of vibrations per second in the air. The commonest instrument for the determination of pitch is the siren. The siren in principle is a revolving disk with a given number of holes in it, through which air can be driven. By means of a mechanical counter the number of revolutions of the disk per second can be seen. Multiplying the number of holes in the disk by the number of revolutions per second it makes, one gets the number of vibrations per second produced, which is the pitch of the sound. The ear is of no avail in the experiment.

In comparing some note of given pitch, however, with the siren in order to determine the pitch of the given note, the ear is often used to tell when the note of the siren is the same as that of the given note. But if great accuracy is desired, as in the comparison of tuning-forks, the ear is deprived even of this function. For when a mirror is attached to the end of a vibrating fork and made to cast a beam of light on a screen, the light will make a characteristic line on the screen. When, then, a beam of light has been reflected to this first fork from a mirror attached to another fork vibrating at right angles to the first one, certain characteristic figures (Lissajous's figures) will be made on the screen, which determine with great accuracy the relative frequencies of the two forks. Thus vision again displaces hearing.

In determining loudness, hearing alone is used. But very little space in physics is devoted to the loudness of sound. It is usually just mentioned. The following quotation from Poynting is significant: "Up to the present time no simple and satisfactory method of measuring loudness has been devised, since it never has been of practical importance to obtain a measure."[1] That is to say, scientists have not yet become much interested in the loudness of sound. Hence it is still described in terms of hearing.

Until recently the ear had to be used as a detector in determining the quality of sound, though sight did all the rest of the work. The quality of sound, it was discovered, is attributable to the composition of the waves. Helmholtz devised a scheme to analyze waves by means of resonators—metal bulbs so constructed as to vibrate sympathetically only to a given frequency of vibration. These were put to the ear and the complex sound in question given. If the resonator could be heard, the experimenter might be sure the complex sound had the note of the resonator as one of its components. What the note of the resonator was would have to be determined previously by one of the methods described above for determining pitch. Most of the material in Helmholtz's experiment, therefore, was visual, though the ear had to be employed as a detector.

But Ames writes: "In the best and most recent work on the analysis of sounds, phonographs are used, and the traces magnified."[2] In the best work, therefore, the data are entirely visual.

The most careful experiments on the velocity of sound were performed by Regnault. The source of the sound was the firing of a pistol. As soon as the shot went off, it cut a wire across the muzzle of the pistol. That broke an electric circuit and registered the time of firing on the revolving drum of a chronograph. The sound wave was received at a distant station by a wide cone fixed to a cylinder which was closed at the further end by an india-rubber membrane. In the middle of the membrane was a light metal disk, so that when the membrane was driven back by the impact of the sound wave, the disk touched a metal point, completing an electric circuit which was immediately registered on the drum of the same chronograph that registered the time of firing. The data from the measurement of the distances between the pistol and the membrane and the data from the drum of the chronograph constituted all the data for determining the velocity of sound, and all the data are visual.

For experiments on reflection, refraction, and interference of sound, the ear is sometimes used as a detector, but more frequently Koenig's manometric flame. This flame is a gas jet issuing from a pinhole burner, the pressure of the gas being so regulated that the flame is on the verge of flaring and will flare on the least disturbance in the air. If great accuracy is desired, the flame can be reflected in a revolving mirror in which every movement it makes can be plainly seen. In this form the flame is useful not only as a mere detector, but as a direct means of determining the frequency and composition of sound waves.

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[1] Poynting and Thomson, *A Text-book of Physics*, "Sound," 1914, p. 8.

[2] J. S. Ames, *A Text-book of General Physics*, pp. 396–397.

All the other data in experiments on reflection, refraction, and interference of sound—such as wall surfaces, rudder lenses, and interference tubes, and the various measurements of these—are in visual terms. Hence, when these experiments are carefully performed with Koenig's flame as a detector they are completely in terms of sight.

Summing up, we find that the great bulk of data in the science of sound is visual; that in all the most accurate and careful experiments, visual data alone are used; that in experiments of a lesser degree of accuracy, the ear is used as a detector, but the rest of the data are visual; and that loudness alone appears to depend wholly on auditory data, but that physicists hasten to apologize for their neglect of the subject and the crudeness of their data for it.

Thus the science of sound exhibits a strong tendency away from the sense of hearing in the selection of its data and towards the sense of sight. A similar tendency may be observed in the science of heat, where one would naturally expect the data to be selected by the senses of warmth and cold. Also one would expect chemical data to be selected by the chemical senses, taste and smell. Yet in all these sciences sight is preferred. It is evident, therefore, that sight is the sense chosen to accomplish the first step towards universal comparability of facts, the sense in terms of which all facts must be stated in order to have a lasting scientific value.

But it is also evident that the reduction of all facts to visual data is only a first crude step towards comparability. The second step becomes necessary—the reduction of visual data to units. Examples of scientific units are atoms, molecules, centimeters, grams, ergs, volts, amperes, ether waves, air waves, degrees Centigrade, degrees Fahrenheit, biological cells, *etc., etc.* But what is a scientific unit?

The first notion that occurs to one is that it must be the smallest datum of a group of data—*i. e.,* of a science—for how could a smaller datum be reduced to a larger datum? We are, however, constantly reducing smaller to larger data. The scientific unit of length is the length of a certain platinum bar in Paris when at a temperature of zero degrees Centigrade. It is known as a meter. But most scientific facts are stated in terms of a centimeter, which is a hundredth part of a meter, and it is not infrequent to hear of thousandths of a centimeter or even smaller fractions. The unit of length, therefore, is not the smallest length ever measured in physics, but a relatively long length. Practically all mechanical, electrical, and thermal units are of this kind. On the other hand, there are units that are not divisible, and are consequently the smallest in the science that treats of them: for instance, the cell of biology. Nothing can, therefore, be asserted offhand concerning the size of a scientific unit.

The next thought that occurs to one is that a scientific unit must be a purely arbitrary thing. Under certain circumstances it is arbitrary within limits—arbitrary in the same way the choice of the common denominator of a group of fractions is. Any multiple of the least common denominator of a group of fractions would do for comparing them, but arbitrarily the least common denominator is chosen. The arbitrariness of the choice lies only within the multiples of the least common denominator. The choice of some one among the multiples is necessary. In the same way certain units are arbitrarily chosen, as, for instance, the unit of length. Any length would have done for a unit. The choice was arbitrary among lengths. But the unit was necessarily some length. One can not measure the height of a man by sourness or the distance across the Atlantic by claps of thunder. Yet in certain cases, where, so to speak, there is no multiple, the choice of the unit is absolutely necessary, as, for instance, the atom of chemistry.

A scientific unit, therefore, is not necessarily the smallest datum in a science, nor is it ever entirely an arbitrarily chosen datum. A curious characteristic of some units still remains to be mentioned. A unit need not necessarily be a datum at all. I am thinking of the atom, the air wave, the ether wave, and such units. This characteristic is especially astonishing when one reflects that the first step towards comparability of facts is a reduction of all facts to visual terms. In these units, the labor of that first step is apparently thrown away. Only apparently, however, for in every case of this kind the unit is one that could be seen if vision were sufficiently acute. The unit is in visual terms, though invisible. If it were not in visual terms, it could not possibly make visual data comparable, which is its function.

We may, then, define a scientific unit as an entity in visual terms by means of which visual data are rendered comparable. Those data which a unit renders comparable form a group in virtue of that fact. Such a group is called a science. A science, then, is formed and defined by its units. I say "units" in the plural because in some cases it takes several units to render a group of data comparable, and the science would consequently have to be defined by all the units together. Mechanics is a case in point, where groups of data become comparable only through the combined agency of four units—the centimeter, the gram, the second, and the radian. Usually, however, one unit is enough, as, for instance, in biology the cell, in anthropology the man.

The state of science brought about by the second step in scientific evolution is, then, a multitude of isolated sciences, each of which is defined by one or a few units, which render comparable a large group of facts. There is thus zoology defined by the unit, animal; botany by the unit, plant; biology by the unit, cell; chemistry by the unit, atom; mechanics by the four units just mentioned, *etc.*

But this is manifestly not a final state of science. To have isolated sciences, not to be able to compare the facts of one science with those of another, is too provoking to be long endured. Hence, the third stage in scientific evolution arises, in which units are made comparable with one another. The sign of this stage is the appearance of a distinction between elementary and derived units. As soon as this distinction is recognized, two processes take place: On the one hand, old units defining isolated sciences are ordered and made dependent on one another—some being made elementary, others derived. On the other hand, new derived units spring into existence depending upon the original units which defined the isolated sciences. Altogether, there takes place among the sciences at the same time a tremendous consolidation and a most intricate differentiation.

An example of the first process is the consolidation of botany, zoology, anthropology, physiology, and numberless other more or less isolated sciences of a century ago into the one big science of biology. The cell is the elementary unit from which the units plant, animal, man, tissue are derived. Botany, zoology, anthropology, physiology, *etc.*, are derived sciences dependent on biology.

An example of the second process is mechanics. This science, as I just said, is based upon four elementary units—the centimeter, the gram, the second, and the radian—from which no less than nine derived units have been made. They are the following:

1. $\text{cm.} \times \text{cm.} =$ unit of area, or square cm.
2. $\text{cm.} \times \text{cm.} \times \text{cm.} =$ unit of volume, or cubic cm.
3. $\frac{\text{gm.}}{\text{cm.} \times \text{cm.} \times \text{cm.}} =$ unit of density, unnamed.
4. $\frac{\text{cm.}}{\text{sec.}} =$ unit of velocity, unnamed.
5. $\frac{\text{r}}{\text{sec.}} =$ unit of angle velocity, unnamed.

6. $\frac{\text{cm.}}{\text{sec. x sec.}}$ = unit of acceleration, unnamed.

7. $\frac{\text{gm. x cm.}}{\text{sec.}}$ = unit of momentum, unnamed.

8. $\frac{\text{gm. x cm.}}{\text{sec. x sec.}}$ = unit of force, or dyne.

9. $\frac{\text{gm. x cm. x cm.}}{\text{sec. x sec.}}$ = unit of energy, or erg.

These derived units were quite literally derived from their elementary units. That is to say, the dyne, for instance, was built up out of centimeters, grams, and seconds; it did not break down into centimeters, grams and seconds. The process here is exactly the opposite from the first process, though the result in the two cases is the same, *viz.*, comparability of units. In the former case, analysis shows certain units to be derived from other elementary units. In the latter case, synthesis shows derived units composed of elementary ones. The two processes go on more or less together, and are mutually helpful. For example, by analysis cells have been broken up into their chemical constituents, and thus proved to be units derived from atoms; at the same time, by synthesis atoms have been put together and things that are virtually cells constructed, thus proving again that cells are derived from atoms. At once, the facts of biology and chemistry become comparable.

The final result towards which this third step in the evolution of scientific data aims is a complete comparability of facts throughout the whole range of knowledge, brought about by an arrangement of units such that all units are derived from a certain few elementary ones. Science is already sufficiently advanced to indicate what those elementary units will be. They will be the centimeter, gram, second, and radian.

For all the physical sciences flow directly into these four units. Chemistry is in terms of atoms; and atoms are characterized by their relative weights and are theoretically, at least, regarded as centers of force, both of which facts point to their ultimate reduction into terms of centimeters, grams, seconds, and radians. Biology is founded on the cell, and the cell, as I observed, is derived from the atom, so that ultimately cells also would be derived from centimeters, grams, seconds, and radians. The big established sciences, therefore, —physics, chemistry, and biology—are rapidly rolling towards the consummation of scientific evolution, towards complete comparability of all facts whatsoever through the interpretation of them in terms of the ultimate elementary scientific units, the centimeter, the gram, the second, and the radian.

Thus we see in a wide way what science is doing on its material side. It is making a continuous endeavor to reduce all facts to a single least common denominator through which alone a universal comparison of facts is possible. Its first step in this endeavor is to sift out of the facts all except visual data. Auditory, olfactory, tactual—all kinds of data other than visual data are retained only in the complete absence of pertinent visual data.

The second step is to mold these visual data into a system of units —centimeters, cells, atoms, *etc.*—by means of which bodies of knowledge are separated. Within these bodies of knowledge all facts are comparable, and each body is known as a science. These bodies of knowledge are scattered, more or less isolated, standing to each other very much as one nation stands to another in a nationalistic state of society. There is complete comparability of facts within a body of knowledge defined by scientific units, but there is virtually no comparability of facts between the different bodies of knowledge.

Then the third step is the organization of the units themselves into a system where each unit is comparable with each other unit, and where consequently any fact of any body of knowledge is comparable with any fact of any other body of knowledge. This step is accomplished by subordinating units to one another, and calling the fundamental units elementary and the subordinate ones derived. The final result of this third step will be the subordination of all units to a few fundamental ones. We are even able to foretell what these fundamental units will be. They will be the centimeter, the gram, the second, and the radian. When all science is interpretable in terms of these units, it will have reached its goal on its material side.

From the crude fact to the visual datum, from the visual datum to the scientific unit, from the scientific unit to the organization of units, and the ultimate interpretation of the fact in terms of centimeters, grams, seconds, and radians—we see the transformation of sensation into scientific knowledge.

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DUALITY AND DUALISM

IN what follows I am not to be understood as arguing in behalf of epistemological monism. So far as I know I have not a chemical trace of interest in it. And if my argument does not on that account run in behalf of epistemological dualism, it is because dualism appears to me only two monisms stuck loosely together, so that all the difficulties in monism are in it multiplied by two. If my position must be labeled, I should prefer to call it empirical pluralism, for it is actuated by respect for the plurality of observable facts.